If you are using a printed copy of this procedure, and not the on-screen version, then you MUST make sure the dates at the bottom of the printed copy and the on-screen version match.
The on-screen version of the Collider-Accelerator Department Procedure is the Official Version.
Hard copies of all signed, official, C-A Operating Procedures are available by contacting the ESSHQ Procedures Coordinator, Bldg. 911A

9.1.15.a BLIP Target and Canning Record

Hand Processed Changes

HPC No.	Date	Page Nos.	Initials
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Approved: ___________***Signature with Date on File***_______________
Collider-Accelerator Department Chairman Date

D. Beavis, S. Smith

Note 1: Uncontrolled copy printed from electronic master that is valid at time of printing. Always check that you have the latest revision of this document before use.

Note2: Leave no blanks. Indicate 'Not Applicable (N/A)', where appropriate.

Title and Preparer	
Production of High Specific Activity ^{186}Re from Tungsten Metal for Research and Clinical Applications By Suzanne Smith and Matt Gott	
Instructions	
Description	**Page No.**
1. Overview [short summary of purpose of experiment; name of principle investigator and researcher involved]	4
2. Target Material and Properties – [Provide physical properties of <u>each component/material</u> to be irradiated]	5
3. Target Canning Process – [provide images or drawings and reference the OPM procedures for closing and opening of target can]	6
4. Beam Characteristics [define required beam on target and total current required]	7
5. Proposed Experiment [Provide general description of a) how target will be supplied BLIP, b) target array in box 1 and box 2; c) thermal analysis of target material and target can d) transport of irradiated target to TPL; target opening and processing at TPL and e) disposal of waste. List persons responsible for conducting each task. If others are required to assist in the research irradiation, define level of skill of staff and contact time.]	7
a. Procedure for Irradiation of Target Material BLIP [Summarize steps for experiment including specialist and contact hours required for task]	7
b. Target Array [Define proposed target array for box 1 and box 2 including SRIM calculated entry and exit energy for each layer. Provide physical dimension of degraders, target can, materials and water gaps]	7
c. Thermal Analysis of Target Materials and Target Can [Provide full description of data provide to specialist for calculations and any assumption made on material for calculations]	7

1. Overview

Production of High Specific Activity ^{186}Re from W for Research and Clinical Applications.

Principal Investigator: Suzanne V Smith (Production Manager, MIRP BNL)
Researcher: Matthew D Gott (Visiting PhD Student, Univ of Missouri)

Background: The irradiation described in this safety submission is part of planned research program entitled "Targetry Development and Production of ^{186}Re and ^{72}As for Research and Radiopharmaceutical Applications." It is a collaborative research program between Brookhaven and the University of Missouri. Matthew Gott received funding from the DOE Office of Science to visit Brookhaven to work on this project with Suzanne Smith.

The work described here is to specifically address the production of high specific activity ^{186}Re. ^{186}Re is a β^- emitter with favorable nuclear properties that makes it an ideal therapeutic surrogate for ^{99m}Tc.

This safety submission outlines the issues related to the production of ^{186}Re from a tungsten metal foil. The main nuclear reaction of interest in this irradiation is $^{186}W(p, n)^{186}Re$. The irradiation will involve exposing the tungsten metal foil at an average current of 115 μA for 1 hour.

Once irradiated, the target (containing the tungsten disc) will be transported to Target Processing Lab (TPL) in the transport cask, where it will be disassembled in a hot cell. The tungsten foil will then be transferred to one of radiochemistry laboratories (either 57a or 59) to test an established separation method developed by Matt Gott (at MU).

2. Target Material and Properties

Target Name:	Tungsten Foil	**Target & Canning No.** *Assign unique no.* (year-00x)	

Target Material Properties

Purity or Grade	Tungsten Foil (99.95%) (See Appendix 1 for Analysis)			
Chemical Formula	W			
Physical Characteristics at 70 °F or 21 °C	Solid			
Physical Form	**Foil**	Yes	**Powder**	No
	Diameter (inches/mm)	1 inch / 25 mm	**Pressed (Torr)**	N/A
Elements (%)	W (99.95%)			
Melting Point	3422	**°C**	6192	**°F**
Boiling Point	5930	**°C**	10706	**°F**
Thermal Conductivity	173 **$W.m^{-1}.K^{-1}$**	**Temperature dependence**	***(if available)***	
Density	19.25		**g/cm^3**	
Specific Heat	133		**J/kg.K**	

Target Material Reactions / Properties

Does the Target material react with any of the following?	**Aluminum**	No	**Air**	No	**CO_2**	No
	H_2O	No	**Lead**	No	**Zinc**	No
	Inconel 600	No	**S/Steel**	No	**Copper**	No

Canning Material Properties

Chemical Formula	Aluminum (6061)			
Can Wall Thickness (inches/mm)	0.02 inch / 0.508 mm			
Can Dimensions (inches/mm)	**Can Diameter** 2.75 in / 69.85 mm **Can Width 0.48** in / 12.19 mm			
Melting Point	660.32	**°C**	1220	**°F**
Thermal Conductivity	205 **$W.m^{-1}.K^{-1}$**	**Temperature dependence** *(if available)*		
Density	2.698	**g/cm^3**		
Specific Heat	910		**J/kg.K**	

3. Target Canning Process

Tungsten metal foil (99.95%) was purchased from Alfa Aesar and will be cut to the appropriate diameter (2.54 cm/1 inch). The tungsten foil will be sealed in the screw bolted aluminum can (figure 1 Appendix 4) within in a glove box under helium gas. The sealed aluminum can (containing the tungsten) will be leak tested for helium prior to placing it within the target assembly box behind the ^{82}Sr target array. A new degrader will be substituted for the current vacuum degrader box to ensure there is room within the box for the target. Selected degraders will be positioned within the target array to ensure optimum proton entry energy into the tungsten foil and to minimize the activation of water (see Appendix 2 and 3 for old and new target array).

4. Beam		
Maximum Instantaneous Current Desired	40000	**µA**
Average Current Desired	115	**µA**
Total Integrated Current Desired	115	**µA - hrs**
Maximum Proton Energy on Target Material	~5	**MeV**

5. Experiment

5.a Procedure for irradiation of target material in BLIP: The linac beam will be tuned to 116.8 MeV and the target array described in C-A-OPM 19.17.20a (See Appendix 2) will be modified behind the second RbCl target to ensure entry proton energy into the tungsten target will be approximately 5 MeV (See Appendix 3). The target will be exposed to an **average current of 115 µA for 1 hour.** The irradiated tungsten target will be removed from beam and will be checked for radiation dose prior to transport to TPL in the transport cask (as per RWP: BLIP-15-007). If the radiation dose from the target is too high to comply with the specified RWP, it will be allowed to decay in the BLIP hot cell for 24 hours prior to transport to the TPL hot cell.

5.b Target array in Box 1 and Box 2: The proton entry energy into the target assembly box will be set to 117 MeV. For the new target array, entry and exit proton energies for each degrader after the second RbCl target and into tungsten foil were calculated using TRIM and SRIM (see Appendix 3).

5.c Thermal analysis of target material and target can (attach analyses if any): The steady state thermal analysis of the irradiated tungsten foil and aluminum can was conducted using ANSYS software. Under the experimental conditions described, the maximum achievable temperature for the tungsten foil and the aluminum can were found to be 316°C and 228°C, respectively. These are well within the melting point thresholds for each component (i.e. 3422 °C for W and 660 °C). Details of the thermal analysis are given in Appendix 5.

5.d Transport of irradiated tungsten foil: As described in section **5.a** above.

5.e Disposal of waste: The aluminum can will be disposed with usual radioactive waste stream of the MIRP program. The liquid waste will be disposed in D tank system as described in OPM 19.30.3.

6. Activation Analysis of Target Material and Can

A conservative activation analysis was conducted using the increased isotope production rate at 10 MeV for the full irradiation period (i.e. 115 µA for 1 hour). The list of radionuclides produced from irradiating tungsten metal and their respective yield is given in Appendix 6. For the tungsten foil, the primary isotopes that will be present are $^{182a,182b,186}Re$ with smaller quantities of $^{183,184}Re$, and ^{183}Ta.

Decay Requirements

If necessary, the irradiated target will be allowed to decay for 24 hours prior to transport to hot cells in the TPL (as per RWP: BLIP-15-007). More specifically, for transport of radioactive sources from BLIP to TPL, the dose in the general area must be ≤ 2 mR/h and the dose on contact must be ≤ 100 mR/h.

The irradiated target will be opened in a hot cell in the TPL and the tungsten foil will be removed for further chemical processing and analysis in Lab 57a. According to RWP: RRPL-14-024 for Lab 57A, the dose in the general area must be ≤ 0.2 mR/h and ≤ 5 mR/h on contact, while the dose in the work area (fume hood) must be ≤ 100 mR/h at 30 cm from the source and ≤ 15 mR/h to the whole body.

7. Expected Dose Rate

The dose rate from the irradiated tungsten foil was calculated using Microshield. They are based on the maximum quantities of radioisotopes produced using an average current of 115 µA over 1 hour. (See 15 MeV data in Appendix 6)

Shielding Configuration		Dose at EOB (mR/h)	Dose after 24 hour decay (mR/h)
Tungsten Foil inside Hot Cell	minimum	0.024	0.012
	maximum	0.095	0.052

8. Additional Safety Requirements

NIL

9. Special Operating Instructions

Supporting Documentation

References	1) Lapi et al.; *Appl. Radiat. Isot.,* **2007**, 65, 345-349. 2) Tarkanyi et al.; *Nucl. Instr. Meth. Phys. B,* **2006**, 252, 160-174. 3) Description of processing of tungsten target attached in paper entitled Radiochemical Study of Re/W Adsorption Behaviour on a Strongly Basic Anion Exchange Resin, *Radiochemica Acta*. **2014**, *102(4),* 325-332.
Calculations	Heat calculations checked by Chris Cullen, CAD, BNL.

Appendix 1.

Certificate of Analysis for Tungsten Metal Foil from Alfa Aesar

Product No.: 10416

Product: Tungsten Foil, 99.95% (metals basis)

Lot No.: N09B003

W			> 99.95 %
Al	< 0.002 %	Mn	< 0.002 %
C	< 0.005 %	Ni	< 0.003 %
Ca	< 0.003 %	Pb	< 0.002 %
Cr	< 0.002 %	Si	< 0.002 %
Cu	< 0.002 %	Sn	< 0.002 %
Fe	< 0.003 %	Ti	< 0.002 %
Mg	< 0.002 %		

Appendix 2.

Current Sr-82 Target Array from C-A-OPM 19.17.20a

Layer No	Layer	Layer Material	Thickness Inch	Thickness mm	Entry Proton Energy (MeV)	Exit Proton Energy (MeV)
	Window 1	Beryllium	0.012	0.305	116.8	116.5
	Window 2	AlBeMet	0.012	0.305	116.5	116.2
	Beam Line Window	Stainless Steel	0.031	0.787	116.2	113.3
	Water Gap	Water	0.106	2.692	113.3	111.5
	Box Window	Stainless Steel	0.020	0.508	111.5	109.6
1	Water Gap	Water	0.200	5.080	109.6	106.1
~~2~~	~~SS Degrader~~	~~Stainless Steel~~	~~0.029~~	~~0.737~~	~~106.1~~	~~103.7~~
~~3~~	~~Vacuum Box~~	~~Vacuum Box~~	~~0.596~~	~~15.140~~	~~103.7~~	~~103.7~~
~~4~~	~~SS Degrader~~	~~Stainless Steel~~	~~0.029~~	~~0.737~~	~~103.7~~	~~100.2~~
5	Water Gap	Water	0.200	5.080	100.2	96.5
6	Target Front	Inconel 600	0.012	0.305	96.5	95.2
7	RbCl Target 1	RbCl	0.646	16.400	95.2	73.7
8	Target Back	Inconel 600	0.012	0.305	73.7	72.1
9	Water	Water	0.200	5.080	72.1	67.2
10	Target Front	Inconel 600	0.012	0.305	67.2	65.5
11	RbCl Target 2	RbCl	0.500	12.700	65.5	42.7
12	Target Back	Inconel 600	0.012	0.305	42.7	40.2
13	Water Gap	Water	0.200	5.080	40.2	32.2
~~14~~	~~Cu Degrader~~	~~Copper~~	~~0.220~~	~~5.590~~	~~32.2~~	~~STOP~~
15	Box Window	Stainless Steel	0.020	0.508	NIL	

A modification to the standard C-A-OPM 19.17.20a ^{82}Sr target array is being proposed in order to conduct the tungsten foil irradiations. The changes include:

1) Substituting the vacuum box with a 0.58" stainless steel degrader to achieve the appropriate beam degradation specific for needs for ^{82}Sr production. This change will provide for more space in the target assembly box that will allow positioning of the aluminum can target behind the RbCl targets.
2) Replacing the copper degrader (originally at the back of the RbCl target) with a new aluminum degrader.
3) The new target array is illustrated in Appendix 3.

Appendix 3.

New Target Array for Irradiation of Tungsten Foil in Al Can (Sr-82_W_02)

Entry and Exit Proton Energies for Target determined using TRIM and SRIM

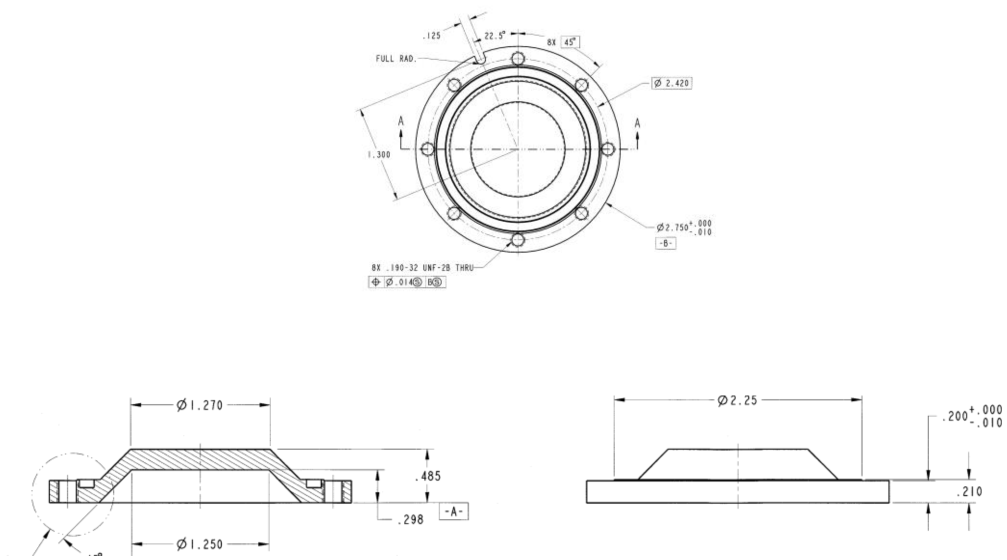
Layer No.	Layer	Layer Material	Thickness Inch	Thickness mm	Entry Proton Energy (MeV)	Exit Proton Energy (MeV)
	Window 1	Beryllium	0.012	0.305	116.8	116.5
	Window 2	AlBeMet	0.012	0.305	116.5	116.2
	Beam Line	Stainless	0.031	0.787	116.2	113.3
	Water Gap	Water	0.106	2.692	113.3	111.5
	Box Window	Stainless	0.020	0.508	111.5	109.6
1	Water Gap	Water	0.200	5.080	109.6	106.1
2	SS Degrader	Stainless	0.058	1.473	106.1	100.2
3	Water Gap	Water	0.200	5.080	100.2	96.5
4	Target Front	Inconel 600	0.012	0.305	96.5	95.2
5	RbCl Target 1	RbCl	0.646	16.400	95.2	73.7
6	Target Back	Inconel 600	0.012	0.305	73.7	72.1
7	Water	Water	0.200	5.080	72.1	67.2
8	Target Front	Inconel 600	0.012	0.305	67.2	65.5
9	RbCl Target 2	RbCl	0.500	12.700	65.5	42.7
10	Target Back	Inconel 600	0.012	0.305	42.7	40.2
11	Water Gap	Water	0.200	5.080	40.2	31.7
12	Al Degrader	Aluminum	0.068	1.720	31.7	24.8
13	Water Gap	Water	0.200	5.080	24.8	9.8
14	Target Front	Aluminium	0.020	0.508	9.8	4.4
15	W Metal Target	Tungsten	0.002	0.050	4.4	1.6
16	Target Back	Aluminium	0.178	4.521	1.6	NIL
17	Water Gap	Water	0.298	7.569	NIL	NIL
18	Water Gap	Water	0.100	2.540	NIL	NIL
19	Al Degrader	Aluminum	0.056	1.422	NIL	NIL
	Box Window	Stainless	0.020	0.508	NIL	NIL

Sr-82_W_02 Target Array Updated with Data from Short Tungsten Foil Irradiations

10	Target Back	Inconel 600	0.012	0.305	43.7	41.2
11	Water Gap	Water	0.200	5.080	41.2	33.0
12	Al Degrader	Aluminum	0.068	1.720	33.0	26.2
13	Water Gap	Water	0.200	5.080	26.2	12.5
14	Target Front	Aluminium	0.020	0.508	12.5	8.3
15	W Metal Target	Tungsten	0.002	0.050	8.3	6.4
16	Target Back	Aluminium	0.178	4.521	6.4	NIL
17	Water Gap	Water	0.298	7.569	NIL	NIL
18	Water Gap	Water	0.100	2.540	NIL	NIL
19	Al Degrader	Aluminum	0.056	1.422	NIL	NIL
	Box Window	Stainless	0.020	0.508	NIL	NIL

Appendix 4.

Drawing of Aluminum Screw Bolted Target Can and Loading Procedure.



Target Can – Aluminum Bolted (extract from D25-M-3186)

Procedure for loading of target into Aluminum Bolted Can

Aluminum Bolted Can – *modification for target.*

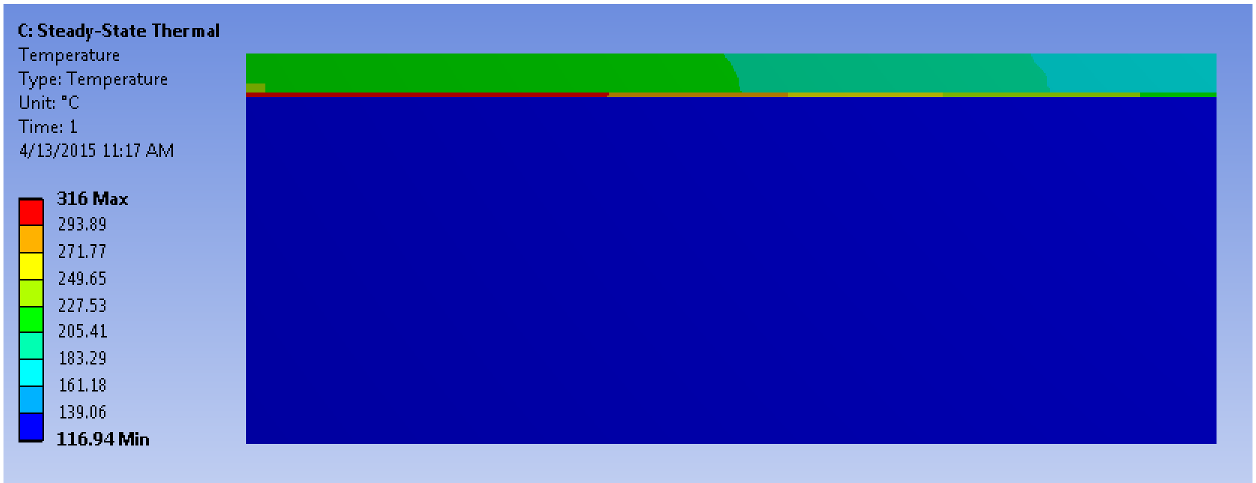
1. The aluminum capsule consists of two parts referred to as upper half (blueprint D25-M-3188), normally positioned upstream beam entry and lower half (blueprint D25-M-3187) positioned downstream (beam exit) that are secured together with eight Allen screws located at the periphery of the target.
2. The water-tight seal is ensured by a c-ring
3. In the center of the lower half there is a well, which is designed to hold target material. It is machined specifically for each target. In this study, 0.002 inch depth for the tungsten foil with a diameter of 1.0 inch.
4. The tailoring of the target well is to ensure optimal thermal conductivity.

Loading of Target Material into Aluminum Bolted Can.

a. Label the upper part placing the letter stamps between the screw holes
b. Cut tungsten foil to 1.0-inch diameter circles ensuring they fit the machined well of the aluminum bolted can.
c. Clean the well of target can and c-ring with acetone and leave to air dry.
d. Place the c-ring in the grove of the lower half of the capsule
e. Place the tungsten foil in the well.
f. Position the upper half of the capsule on top of the lower half and align the indexing slits
g. Insert eight Allen screws into the holes individually secure in the following order : position 12-6-9-3-11-4-1-7 o'clock
h. Create a target card as per C-A-OPM-ATT 19.3.6.2.a
i. Transfer loaded target can to BLIP operator for loading into target assembly.

Appendix 5.

Solid State Thermal Analysis



Calculation conditions: 2D Axi-symmetric model, 0.002" thick tungsten foil in a bolted aluminum can, Steady-state analysis, 2000 W/m^2.°C thermal contact resistance between each layer, 5000 W/m^2.°C water cooling convection on exterior, Gaussian internal heat generation for all bodies.

Experimental conditions used for the calculations: 116.8 MeV protons (entry to target assembly box), **average current of 115 µA for 1 hour** assumed **60% beam on target**. Total energy deposited in the tungsten foil is **1.9 MeV** as given in target array in Appendix 3. Analysis shows the maximum achievable temperature for the tungsten foil and the aluminum can were found to be **316° C and 228° C,** respectively. These values are well below the respective melting points.

Appendix 6.

Literature Cross Sections and Calculated Activities for Anticipated Isotopes for Os Disc

Radioisotopes	σ (mb) at 10 MeV	$t_{1/2}$ of product (hours)	Calculated Activity (mCi) 1 hour irradiation	Calculated Activity (mCi) at Higher and Lower Average Proton Energies	
				5 MeV	15 MeV
Re-181	0.00	19.9	0.00	0.00	100.10
Re-182 (a)	8.02	12.7	9.49	0.00	20.32
Re-182 (b)	86.53	64.0	4.34	1.54	24.47
Re-183	46.25	1680	0.19	0.00	1.12
Re-184	59.74	849.6	0.50	0.00	0.15
Re-184m	0.00	4056	0.00	0.00	0.00
Re-186	62.26	89.23	4.91	1.51	1.58
Ta-177	0.00	56.56	0.00	0.00	6.69
Ta-183	1.14	122.4	0.07	0.00	0.92

Appendix 7.

Identifiable Gamma Energies for Anticipated Isotopes for W Foil

Isotope	Half-Life	Gammas (keV)	Intensity (%)
Re-181	19.9 h	365.5	56
Re-182	64.0 h	169.2	11.4
		1121.4	22.1
Re-182m	12.7 h	1121.4	22.1
Re-183	70.0 d	162.3	23.2
Re-184	35.4 d	792.1	37.7
Re-184m	169 d	104.7	13.6
		792.1	3.69
Re-186	3.718 d	137.2	9.47
Ta-177	56.6 h	112.9	7.2
Ta-183	5.1 d	246.24	27
		162.3	4.9
Decay Daughter:			
W-181	121.2 d	136.3	0.03